A WARM WINTER (1920-21) FOLLOWED BY A WARM SUMMER.

By ALFRED J. HENRY, Meteorologist.

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SYNOPSIS.

This paper is in the nature of a preliminary report on the period of abnormal warmth in the United States and Canada which began in September, 1920, and ended with July, 1921. The location of the areas of maximum positive departure of temperature from the normal from month to month are traced and three periods of abnormal warmth are distinguished. The end of each period of abnormal warmth is evidently marked by a brief and ineffective reaction to lower temperature which soon gave way to a second and third period of unusual warmth.

The meteorological conditions as to pressure, over the United States and the adjacent oceans, the prevailing winds, the number of areas of low pressure (cyclones) plotted during the 11 months are briefly discussed and the most important conclusion reached will be found in the closing paragraph.

The belief that one extreme of temperature, such as a prolonged period of high temperature will be followed by a reaction to lower temperature is held by many. It is not the purpose of the writer to discuss the foundations upon which this belief rests, but rather to put on record the salient features of a very unusual period of sustained high temperature which has characterized the weather of the last 11 months. Added interest is lent the subject by reason of the prevalence of similar conditions over large portions of the Northern Hemisphere.

The temperature distribution in United States and and southern Canada.—A casual inspection of the records for northeastern United States is apt to create the impression that mean temperature has been continuously above normal since September, 1920, with the single exception of November of that year. Further consideration leads to the view that there were as many as three separate periods of maximum warmth separated by brief and ineffective reactions toward lower temperature. These will be described in order: First period: Beginning with September, 1920, mean temperature in southern Canada and generally in the United States except over the Plateau region was in excess of normal by amounts not exceeding 6°. In October, 1920, while the regional distribution of positive departures was about the same as in September the amplitude of the variation had increased to 10° along the Canadian border and in the upper Lake region. The region of maximum positive departure was shifted somewhat to the eastward as compared with the previous month and there was a distinct diminution of the amplitude of the variation in the far Canadian northwest which with a change in sign of the variations is considered as indicating the termination of the first period. The Plateau region continued to show a negative departures as in the previous month.

The second period.—In November, 1920, the region of maximum positive departures was again in the Canadian northwest, whereas temperature in large portions of the United States was below the average of the season. This month appears to mark the beginning of the second period. In December, 1920, the region of maximum warmth remained in Canada and while positive departures prevailed generally in the United States; temperature was still below normal in Wyoming and thence southward to the southern border and westward to Arizona. With the beginning of the new year and continuing through March there appears to have been an intensification of the influences which produced the abnormalites of the previous months; the amplitude of the variations increased to 15° and 16° in southern Saskatchewan and northern Montana, in February, 1921. The area of positive departures in January, 1921, extended from that Province southeastward to Iowa and Nebraska and by the end of February had extended several hundred miles farther to the southeast. A decrease in the amplitude of the variations in the Canadian northwest was not noticed until March, 1921. This month witnessed the shifting of the region of maximum positive variation from the Missouri Valley to the lower Lake region and the Middle Atlantic States and a decrease in the amplitude of the variations. The passage of a cold wave over the region east of the Rockies at the close of the month definitely ended the second period of unusual warmth. The movement of this cold wave was the beginning of a series of incursions of polar air, which continued in April and to a less extent in May.

The third period.—The long period of high temperature which culminated in March was followed by a reaction toward lower temperature in April, but the incursions of cold air as mentioned in the preceding paragraph were not frequent enough to overcome the accumulation of relatively warm air in northeastern districts, and the record for the month for the United States as a whole shows a positive temperature departure of 9° in the Lake region, notwithstanding that subnormal temperatures prevailed in western districts. May, 1921, was a month of nearly normal temperature, although it also marks the beginning of another period of high temperatures in the Canadian northwest, which continued during June and overspread the greater part of the United States. During July the region of maximum departure was found over the Lake region and the St. Lawrence Valley. This, the third period of abnormal warmth, endured for two months, and has thus given character to the summer regardless of the conditions in August.

Chart IV of this REVIEW shows the departure of temperature from the normal in July for both Canadian and United States stations.

It may be of interest to ascertain the vertical extent of the temperature abnormality as shown by kite observations.

The mean temperature in the free air above Ellendale, N. Dak., and Drexel, Nebr., month of June, 1921.—At both of these stations the free-air temperatures up to 4,000 meters (13,123 feet) was above the average almost as much as on the surface. For July, however, the free-air temperatures at Drexel up to about 1,100 meters above the surface were below the average and above the average at the higher levels. The months of January and February were abnormally warm at both stations and in the free air up to the greatest heights reached.

Some of the economic results.—According to a report from the Bureau of Markets and Crop Estimates of the Department of Agriculture, there was an estimated shrinkage of more than a quarter of a billion dollars in the value of prospective crops in the United States during July. This shrinkage must be attributed to the cumulative effect of high temperature and insufficient rainfall. Incomplete reports from other countries indicate that similar weather conditions have prevailed in large parts of the Northern Hemisphere. Such widespread and long-continued adverse meteorological conditions must seriously affect economic conditions for some time to come.

Chart VIII of this REVIEW, reproduced from the National Weather and Crop Bulletin of August 16, shows the percentage of the normal precipitation March 1 to

July 31 received in various parts of the country. As may be seen from the chart, but few localities received as little as 50 per cent of the normal, while there are several rather large areas over which precipitation was considerably above the normal. The most extensive area—the Rocky Mountain region—having an excess of precipitation, very nearly coincides with the region having the least excess of temperature above the normal.

East of the Mississippi the areas having the greatest deficiency in precipitation are found in the extreme southern portions of Illinois, southwestern Indiana, and adjoining portions of Kentucky, also the larger part of Tennessee, extreme northwestern Georgia, the region about Lake Ontario, and one or two other districts as shown by the chart. The vagaries of geographic distribution are illustrated by the Florida Peninsula, where the southeast coast has a percentage of but 66, while Tampa, on the west coast, has 122.

THE CAUSES OF THE PHENOMENA.

The question of the highest interest to meteorologists is that of discovering, if possible, some clue to the cause or causes of the phenomena. Unfortunately, the results of meteorological observations in all parts of the world are not available until after the lapse of several months after the observations have been made. In what follows such facts as are now available will be presented, reserving for the future a more complete discussion after the observational material shall become available.

The apparent place of origin of the abnormal warmth was in the Provinces of northwest Canada, spreading thence southeastward over the United States.

The lack of snow cover in March, 1921.—The lack of a snow cover in Alberta and southern Saskatchewan, and generally in the United States, on March 1, 1921, was doubtless an important contributing factor in the cause of the unusually high temperature in that and subsequent months.

On the last day of February, 1921, snow in the interior districts of British Columbia was about 30 inches deep, while in Alberta and southern Saskatchewan the ground was bare. In northern Saskatchewan and the greater part of Manitoba the depth was from 2 to 10 inches. In western and southern Ontario the ground was practcally bare the greater part of the month, but a snowfall occurred on the 26th leaving a cover in most places of 2 to 6 inches. In northern Ontario it was from 12 to 20 inches, increasing in depth to the eastward across Quebec to 45 inches near the Gulf of St. Lawrence and Bay of Chaleur, thence diminishing southward to about 4 inches in southern Nova Scotia.[1]

In the United States there was a substantial snow cover in northern New England, and an average of 3 to 4 inches in the Lake Superior region; in all other parts of the country except the high mountains of the West,—and relative area of these is negligible,—the ground was bare.

A quantitative statement of the amount of solar energy required to melt a snow cover of a given depth would be interesting and instructive, but there are difficulties in the way of determining that amount even approximately. Dorno[2] gives the albedo of a snow surface as from 60 to 74 per cent, the latter for freshly fallen snow, as compared with 6 to 7 per cent for grass-covered ground and 2 per cent for a water surface. Thus it is seen that the presence of a snow cover must greatly retard the warming of the atmosphere and the absence of such a cover must greatly contribute to the warmth of the lower layers for reasons that need not be given here. Another influence that would doubtless result from an absence of snow in Alberta and Saskatchewan would be to retard the Equatorward flow of polar air. It is well established that the presence of a snow cover is helpful in building and sustaining anticyclonic systems. Consider then the polar basin as an immense reservoir of cold air which in the natural course of events is discharged toward the Equator in anticyclonic systems having their apparent origin in the Canadian northwest. It is conceivable and probable that the bare ground in the Provinces named above was indirectly responsible for the absence of anticyclones in March, 1921. The discharge of polar air evidently takes place at that point where the temperature conditions at the surface are most favorable, whether in the interior of the North American Continent, over Greenland or Siberia.

The pressure distribution of July, 1921.—From the daily weather maps of the Northern Hemisphere, incomplete as they are, we get a broader view of the weather controls of the month than is afforded by a consideration of the data for the North American Continent alone. The outstanding feature of the month was the domination of Oceanic HIGHS on both the Atlantic and the Pacific. At times these HIGHS extended over the adjacent land areas but with different influences upon the weather according to the side of the continent involved.

The Pacific HIGH impinged upon the coast in somewhat higher latitudes than usual, and an unusually large number of weak offshoots therefrom have been plotted on Chart II. Some of these HIGHS made but a short invasion into the continental interior. In but two cases was it possible to plot the path of these HIGHS nearly across the continent, and in each of the cases so plotted the intensity of the HIGH, as judged by the barometer level therein, increased slightly as Atlantic coast districts were reached. The visible effect of the HIGH as it merged with relatively high pressure over the Atlantic was to form a protuberance on the northern or western sides of the then existing Oceanic HIGH.

The most striking example of the Oceanic HIGH being augmented by the approach of continental HIGHS was on the 10th, when the Atlantic HIGH, which at that time stretched in the shape of a vast crescent from the British Isles to the Carolina coasts by way of the Azores, was reinforced at Bermuda by a rise of a tenth of an inch in pressure in 12 hours and a total rise of 0.22 inch in 48 hours, or from 30.14 on afternoon of the 9th to 30.36 inches on the afternoon of the 11th. While this change was taking place in the western horn of the crescent the eastern horn was being displaced by an area of low pressure which passed eastward to the north of Scandinavia on the 12th. The reaction to higher pressure was slow, and there followed a few days of relatively low pressure over southern England and the Channel.

The fact that the rise in pressure at Bermuda before referred to was not associated by a fall in surface temperature leads us to the conclusion that a mass of colder polar air reached the higher levels above that point on the 10th and 11th, possibly in connection with the HIGH that appeared suddenly over the Gulf of St. Lawrence on the morning of the 10th. (See No. IV of Chart II.) Similarly rising pressure at the Azores must be referred to the arrival of fresh masses of polar air aloft.

By the 20th the center of highest pressure had again developed in the eastern horn of the crescent. This condition continued until the 24th, when another low-pressure system passing eastward over northern Scandinavia was the apparent cause of a fall in the pressure over the

[1] Meteorological Service of Canada, report for February, 1921.
[2] *Veröffentlichungen des Preussischen Meteorologischen Instituts*, Nr. 303, Seite, 214.

North Atlantic which extended southward to the Azores, and thus the region of maximum pressure was again shifted to the western portion of the Atlantic. The minimum pressure of the month, at the Azores, 29.88 inches, was recorded on the 26th in connection with the deepest of the traveling depressions that passed eastward over northern Scandinavia.

It is a significant fact that on the same date, the 26th, low pressure systems on the North American Continent began to increase their speed of movement and intensity and that by the end of the month temperature in the Lake region had dropped to normal and below, and on August 1 the same change took place generally over northeastern United States.[3]

Studies of the daily synoptic charts of the North Atlantic lead to the conclusion that the explanation of the Azores HIGH and its temporary extension, either to the northeast or the southwest is to be sought mainly in the day to day atmospheric circulation over the North Atlantic, as modified by the succession of traveling cyclones and anticyclones. The flow of polar air equatorward in the rear of cyclones, appears to reach the Atlantic HIGH over two or possibly three fairly well-defined routes, first, naming them in order from east to west, from Greenland southeastward to the British Isles; second, from the Hudson Bay region southeastward over the Canadian Maritime Provinces; and finally from western Canada, southeastward to and off the Atlantic coast in about 40° north latitude.

The winds.—It has been impossible, owing to the magnitude of the task, to tabulate data of wind direction and movement for the United States as fully as desired. I have, however, considered the record of a single station, Washington, D. C., as representing northeastern United States, and offer the following remarks based thereon.

The most pronounced departure from normal conditions was the diminution in the speed and duration of northwest winds from December, 1920, to July, 1921. The speed diminished from 11 miles per hour in December to 6 in July, and the duration in hours per month from 216 in December to 84 in July. The average for July is 133 hours. The deficit in northwest winds was most in evidence in March, February, June, and July. For these months, especially for March, southerly winds were in excess of the average. For March alone the percentage of northerly winds was but 46 as against 59 for southerly winds. Normally, northerly winds are to southerly in Washington as 4:3.

The number of cyclones.—According to the official count of cyclones as published from month to month in this REVIEW, a total of 164 cyclones appeared on the daily weather maps for the 11 months under consideration. This number is 42 per cent in excess of the 21-year average of Bowie and Weightman (MONTHLY WEATHER REVIEW SUPPLEMENT No. 1, p. 7). According to some writers this fact would indicate an increase in storminess. As a matter of fact it indicates in this case exactly the contrary, viz, a period of *stagnation*.

There is a great difference between a large number of cyclones which for one reason or another are not fully developed and are prevented from moving at the normal speed by the pressure distribution at the moment and a small number of cyclones whose free movement is uninterrupted. Chart III of this REVIEW, for example, portrays the paths of 15 cyclones, 6.4 in excess of the 21-year average.

No significance is attached to the fact that the number of cyclones plotted during the period September, 1920, to July, 1921, was greatly in excess of the average. The significant fact, however, is the control of the winds by the pressure. The excess of southerly winds in March was directly due to the pressure distribution of that month. It was unfortunate for the interests of agriculture that this excess of southerly winds should occur in March, when an advance in the season is fraught with great danger to fruits and crops. The season in Washington, D. C., was three to four weeks in advance of the average; apples were in blossom by the 25th of the month.

The warm weather came to a close, as it usually does, with the advance of a cold wave on the last few days of March. This cold wave was attended by frost and freezing temperature as far south as El Paso, Tex., northern Louisiana, northern Mississippi, northern Alabama, and extreme northwest Georgia. Early fruit suffered much from this and subsequent frosts.[4]

In concluding this brief summary it may be well to refer to the fact that somewhat analogous conditions as to temperature prevailed in March, 1907, with the exception that the preceding month of that year was not so warm as in 1921 and consequently the season was not so far advanced as in the present year. The same drift of surface air from south to north occurred in 1907, and the pressure distribution in the United States at least was somewhat similar. The months of April, May, and the forepart of June, 1907, were, however, exceptionally cold[5] while the reaction to lower temperature in 1921, as already stated, was weak and ineffective. It is believed that the explanation of the low temperature which prevailed in April and May, 1907, is to be found in the movement of HIGHS and LOWS across the United States in those months.

I have ventured the statement elsewhere in this paper that variations in the geographic position and intensity of the so-called "action centers" of the atmosphere are conditioned upon the day-to-day movement of cyclones and anticyclones, at least it so appears for the two centers in the North Atlantic. There is slowly coming to hand data for the Pacific which will throw some light upon the movement of HIGHS and LOWS across that ocean as influencing the position of the Aleutian LOW and the North Pacific HIGH. In any event, the subject is worthy of further study.

CONCLUSIONS.

This preliminary study has not yielded results which may be entitled to much weight; they are put forward, however, as suggestive and indicative of further study along certain lines.

The most important phase of the subject as developed relates to the pressure distribution in one of the so-called world "centers of action"—the Azores HIGH or, more properly, the North Atlantic HIGH. It would seem that the intensity and geographic extension of that HIGH is conditioned upon the movement of traveling cyclones and anticlones in contiguous areas. If this be true in all parts of the world, as it may well be, then the control of the weather must be referred back to the cyclones and anticlones of the time and place. That part of the ocean occupied by North Atlantic HIGH is a region of stagnated air currents except on its western periphery. It is therefore only indirectly concerned in the control of the weather in adjacent regions of the globe. Its position with reference to the path of traveling cyclones is such as to augment the southwesterly winds of trav-

[3] *The Weekly Weather Report* of the British Meteorological Office for the period ending July 30, just received, announces a great change in the weather during the week. Rain fell over most districts, more especially in Scotland and Ireland, although over England rainfall was generally below the normal.

[4] *National Weather and Crop Bulletin* Nos. 13, 14, 15, and 16, Ser. 1921.

[5] A. J. Henry: The Cold Spring of 1907, MO. WEATHER REV. 35:223.

eling cyclones which frequent the North Atlantic, thereby removing a part of the air mass of the HIGH and thus inducing a fall in pressure. When the outflowing winds continue for some time, the level of the barometer sinks and the region of maximum pressure—the crest of the HIGH—is apparently shifted to the south or the west, as the case may be. A shifting of position thus brought about can have little, if any, influence upon the weather of adjacent areas. From this point of view the term "center of action" as ordinarily applied is a misnomer.

The type of weather associated with high temperature in northeastern United States came to an end about the close of July. The change was apparent, in the beginning, in the increase in the depth of cyclonic depressions and a speeding up of their velocity of translation; there was, of course, a correspondingly greater gradient for northerly winds which resulted in the more thorough mixing of the lower strata of the atmosphere and cooler weather. This or a somewhat similar change was observed in Great Britain during the last week of July. Another indication of the change was the sharp fall in the barometer at the Azores on July 26, due, it is believed, to the influence of a northern depression, which at the moment was passing to the eastward over Iceland. The fall in pressure over the Azores indicated first of all that cyclones for the time being, at least, were taking a lower course than formerly, and this fact is always significant in weather forecasting.

It may be recalled that nothing has been developed in the foregoing discussion which would indicate the underlying cause of the very pronounced variation in the mean temperature of January, February, and March, 1921, although the suggestion has been made that the changes in surface cover induced by the continued high temperature of January and February would doubtless strongly influence the weather of subsequent months.

The most pronounced disarrangement of the normal distribution of the meteorological elements during the months of January and February, 1921, was in the pressure distribution. Roughly speaking, it would seem as if the belt of high pressure which encircles the globe about north latitude 35° was temporarily displaced to the northward, and this in turn was responsible for the eastward movement of cyclones in higher latitude than in a normal period. We may then assume that the disturbance which was most pronounced in January, 1921, and was apparently more than local in nature, must be influential in giving character to the weather until once more the normal distribution is restored. It may be seen from Chart VII of the February, 1921, REVIEW that mean pressure for that month still continued relatively high in southern districts of the United States and that the region of maximum pressure for the month appears on the Pacific rather than on the Atlantic coast, as was the case in the previous month. There is no question but that the abnormalities of temperature and precipitation which we have discussed were primarily due to the pressure distribution, but that knowledge brings us no nearer to a solution of the riddle of seasonal weather forecasting.

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THE DEFINITION AND SCOPE OF CLIMATOLOGY: WHEREIN IT IS TO BE DISTINGUISHED FROM METEOROLOGY.

By L. W. C. Bonacina.

[Author's Abstract.]

[27 Tanza Road, Hampstead, London, N. W. 3, July 2, 1921.]

The ordinary distinction which is drawn between meteorology and climatology is vague, and a definition based on sound philosophical principles is needed which will be of practical use for purposes of classification. Climatology is shown to comprise the regional aspects of meteorology; it is Regional Meteorology, and as such the theoretical distinction between the two studies of the atmosphere is in the point of view rather than in the subject matter. If once this theoretical distinction is grasped, it will be found a reliable guide in deciding whether a given subject, problem, or proposition in the science of the earth's atmosphere should be regarded as essentially meteorological or climatological.

Pure meteorology is a part of geophysics. Climatology, on the other hand, involves geographical relationship, and it is shown that a meteorological subject is "climatological" to the extent that interest centers round the locality and reason of weather events. Defined thus on broader lines, climatology is not a mere subsidiary branch of meteorology as is so often stated, but is a collateral aspect of the science of the atmosphere, constituting *regional*, as opposed to *pure*, meteorology. Pure meteorology treats of weather processes as a set of physical changes; climatology is concerned with them as the expression of regional and seasonal influences, involving geographical comparison with other regions. It is clear, further, that in so far as climatology not only describes, but also explains, regional weather it can be built up on a firm basis of geophysics.

Finally, it is indicated that Regional Meteorology or Climatology, in so far as it is a subject which is particularly interested in seasonal periodicities of weather, ought really to be regarded as a study not merely in three, but in four, dimensions, viz—north-south, east-west, up-down, summer-winter—as specified respectively by latitude, longitude, height, and date. (In this connection see also the author's note on "Definition of geography" in *Scot. Geo. Magazine*, April, 1921.)

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CLIMATE DEFINED: ITS CONSTITUENT ELEMENT CAUSATIVE FACTORS.

By L. W. C. Bonacina.

[Author's Abstract.]

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Climate is defined as average regional weather, the term average being used in the true mathematical sense to include the less common, as well as the more common, phases or weather. Thus "climate" really represents a kind of frequency distribution of weather types and phases in a given region. Any phase of weather is an expression of climate. It is pointed out that nearly all writers tend to confuse the notion of a *constituent element* of weather and climate with that of a *causative factor* of the same. The several well-known primary factors which cause or determine the distinctive climate of any region on the earth's surface are briefly reviewed and classified under the following minimum number of categories: (1) Solar constant of radiation, (2) latitude, (3) altitude, (4) land and water distribution, (5) wind belt, (6) land relief, (7) soil conditions, etc., (8) occasional influences, such as volcanic dust in the upper air. The physical effect which these climatic factors individually exert is fairly well understood, but No. 5 is singled out for special consideration in relation to the scope of climatology and forms the topic of the following paper.